UNDERSTANDING, CUSTOMIZING, AND HOT-RODDING YOUR *ETHERWAVE* ® THEREMIN

TABLE OF CONTENTS

INTRODUCTION

We'll first explain how the *Etherwave* converts hand movements into changes in pitch and volume of a musical tone. We hope that this explanation will help you to understand the *Etherwave's* operation, and will provide the information necessary for you to add to and modify your *Etherwave* to meet your individual requirements.

Following our explanation of the *Etherwave's* circuit, we'll describe several useful customizations and 'hot-rod' circuit additions. They range from a simple resistor change to the construction of a complex outboard circuit. Experimenters are welcome to incorporate any or all of these into their Etherwaves. In addition, you are welcome to do your own hot-rod design, providing you have the technical background to understand how your proposed designs will interact with the circuit of the Etherwave itself.

HOW THE *ETHERWAVE* WORKS

There are several *resonant circuits*, or *tuned circuits*, in the *Etherwave* theremin. Since resonant circuits are not as common or accessible in today's electronic gear as they used to be, we'll define some basic terms and concepts that will help you understand how the theremin circuit works.

A resonant circuit consists of a capacitor (sometimes called a condenser) and an inductor (sometimes called a coil). A capacitor is a device consisting of two conductive plates separated by insulating material such as air or polyester. The capacitance of a capacitor depends on the size of the plates and the distance between them. An inductor is a device consisting of a coil of wire, sometimes wrapped around an iron or ferrite core. The inductance of an inductor depends on the number and size of the turns of wire and the material of the core. A resonant circuit has the property that its electrical impedance changes radically within a narrow frequency band, the middle of which is called the *resonant frequency* of the circuit.

HAND CAPACITANCE

When you bring your hand near a theremin antenna, you are actually forming a variable capacitor in which the antenna is one 'plate' and your hand is the other. For the high frequencies and very low currents that we're talking about, your hand is effectively grounded by being attached to your body, so the antenna and your hand form a variable capacitor to ground. We call this variable capacitance *hand capacitance.* You increase the hand capacitance by bringing your hand nearer to the antenna. In normal theremin playing, hand capacitance is less than one picofarad, a very small capacitance change indeed! In addition to hand capacitance, a theremin antenna has a fixed capacitance to ground, which we'll call the *antenna capacitance.* Antenna capacitance depends mostly on the size of the antenna, and is typically 10-15 picofarads.

A large inductor, called the *antenna coil,* is connected to each antenna inside the theremin. The antenna coil, antenna capacitance, and hand capacitance form a resonant circuit (Figure 1). In our design, the resonant frequencies are about 285 kHz for the pitch antenna, and about 450 kHz for the volume antenna. At or near the resonant frequency, a tiny change in hand capacitance results in a larger change in the impedance of the antenna circuit as a whole.

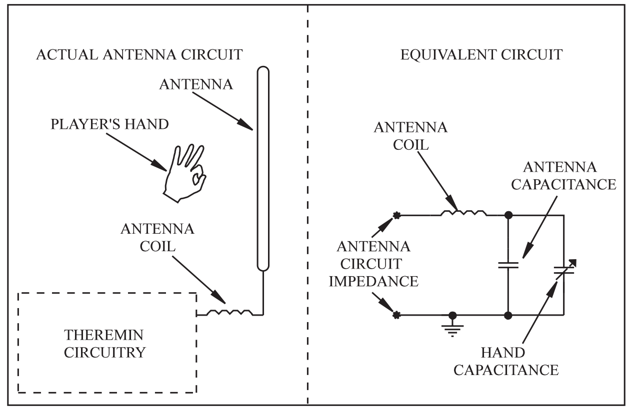


Figure 1 - Equivalent Circuit of Hand Capacitance

THE *ETHERWAVE* CIRCUIT

Before looking at the schematic diagram itself, we'll review the functions of the *Etherwave's* circuit. Figure 2 is a block diagram showing all the circuit functions.

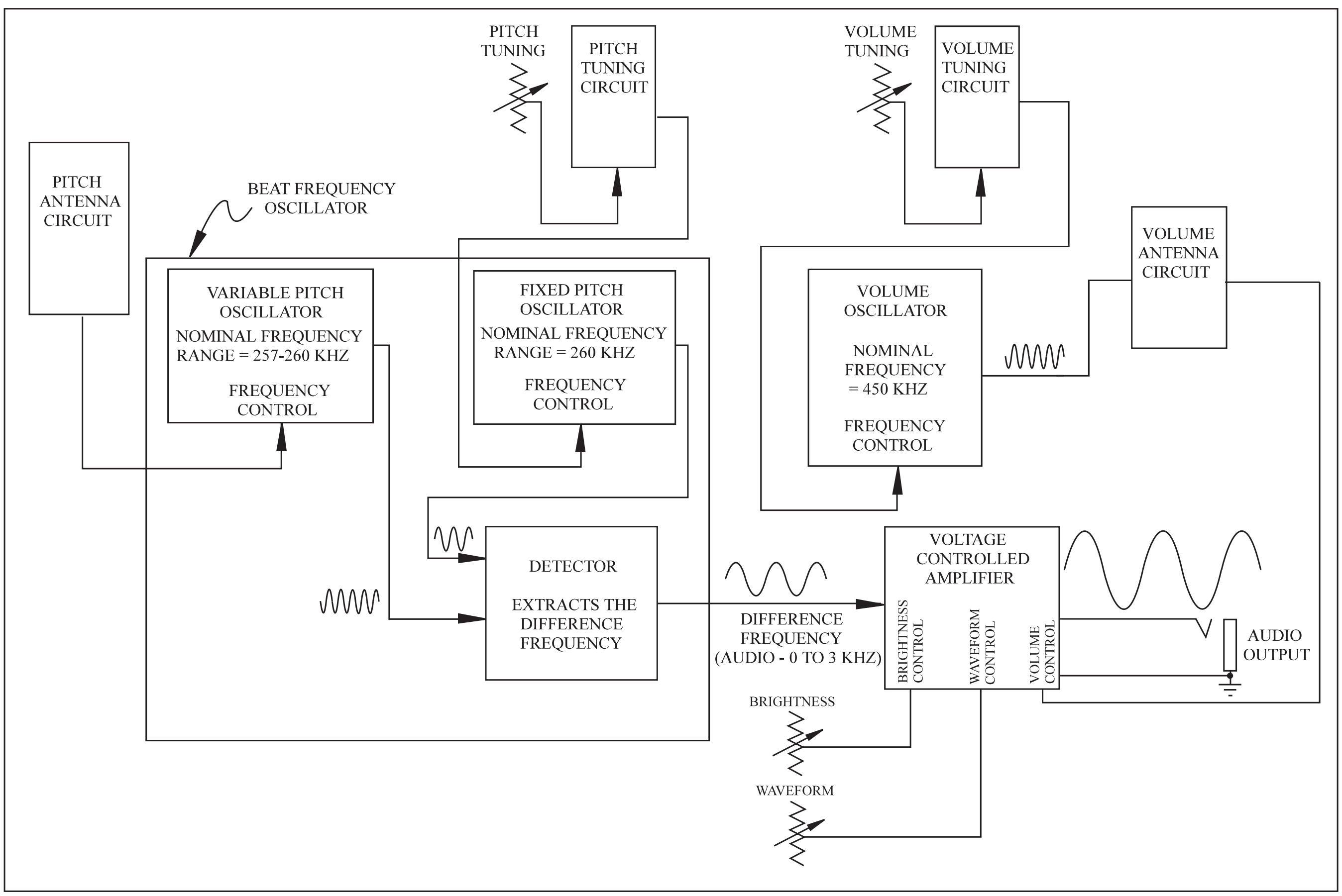


Figure 2 - Etherwave Block Diagram

TONE PRODUCTION AND PITCH CONTROL

The *Etherwave's* tone is produced in a circuit configuration called a *beat frequency oscillator.* It consists of two high-frequency oscillators, plus a detector circuit which extracts the difference frequency, or beat frequency. One of the high-frequency oscillators (called the *fixed pitch oscillator*) operates at about 285 kHz, while the other high-frequency oscillator (called the *variable pitch oscillator*) operates over a range of about 282 - 285 kHz. The difference frequency ranges from zero to about 3 kHz, which is three and a half octaves above middle C.

The pitch antenna circuit is connected to the variable pitch oscillator in such a way that increases in hand capacitance will decrease the variable pitch frequency as much as 3 kHz. This is how the pitch antenna circuit, in conjunction with the beat frequency oscillator circuit, enables the player to cover a usable pitch range of some five octaves (two octaves below to three octaves above middle C) simply by moving her right hand through a distance of two feet or so.

VOLUME CONTROL AND TIMBRE CONTROL

The volume antenna circuit consists of the volume antenna itself, in series with several inductors. It's connected to the output of the *volume oscillator,* which provides a high frequency signal. When the antenna circuit resonant frequency is at or near the volume oscillator frequency, a high frequency current flows through the inductors, which induces a high frequency voltage across each of the inductors. These voltages are at a maximum when the antenna circuit's resonant frequency is exactly the same as the frequency of the volume oscillator, and decrease when the antenna circuit's resonant frequency is decreased by the addition of hand capacitance to the volume antenna. The volume antenna circuit also includes a detector, which converts the high frequency voltage across one of the inductors to a direct (DC) voltage. This voltage, which is called the *volume control voltage,* controls the gain of a voltage-controlled amplifier (VCA). Thus, as the player brings his left hand near the volume antenna, the volume control voltage decreases, the VCA gain decreases, and the audio output signal goes from loud to complete silence. The audio output signal is line level, and may be fed to a line input of a power 7amplifier or mixing console.

Front panel controls include four potentiometers: two for antenna tuning and two for timbre control. The PITCH TUNING potentiometer is connected to the *pitch tuning* circuit, which adjusts the frequency of the fixed pitch oscillator over a small range. Similarly, the VOLUME TUNING potentiometer is connected to the *volume tuning* circuit, which adjusts the frequency of the volume oscillator over a small range. These circuits provide the player with a way of fine-tuning the antenna responses during performance. In earlier theremin designs these tuning functions were implemented with large variable capacitors. Such variable capacitors are no longer generally available at reasonable prices.

The VCA is deliberately designed to distort the difference frequency waveform, thereby adding desirable harmonic content. The BRIGHTNESS and WAVEFORM potentiometers vary the biases on the VCA input, which change the way in which the audio waveform is distorted. The BRIGHTNESS potentiometer determines how much the waveform is distorted, and therefore the amount of the total harmonic content. The WAVEFORM potentiometer determines which harmonics will be strong, and which will be weak. It is similar to a Rectangular Width control on analog synthesizers.
The entire theremin circuit runs on ± 12 volts, which is supplied by a simple, small power supply. Total current consumption is about 30 milliamperes.

A TOUR OF THE SCHEMATIC DIAGRAM

Figure 3 is the schematic diagram of the entire *Etherwave* circuit. Nominal DC levels (as measured with a DC voltmeter) are shown at several points in the circuit. Figure 4 shows the positions of all components on the *Etherwave* circuit board.

The three high frequency oscillators are nearly identical, the differences being in the values of their tuned circuit elements and in the manner in which their frequencies are adjusted.

Q1, Q2, and their associated circuitry comprise the variable pitch oscillator. The frequency of oscillation is determined primarily by the resonant

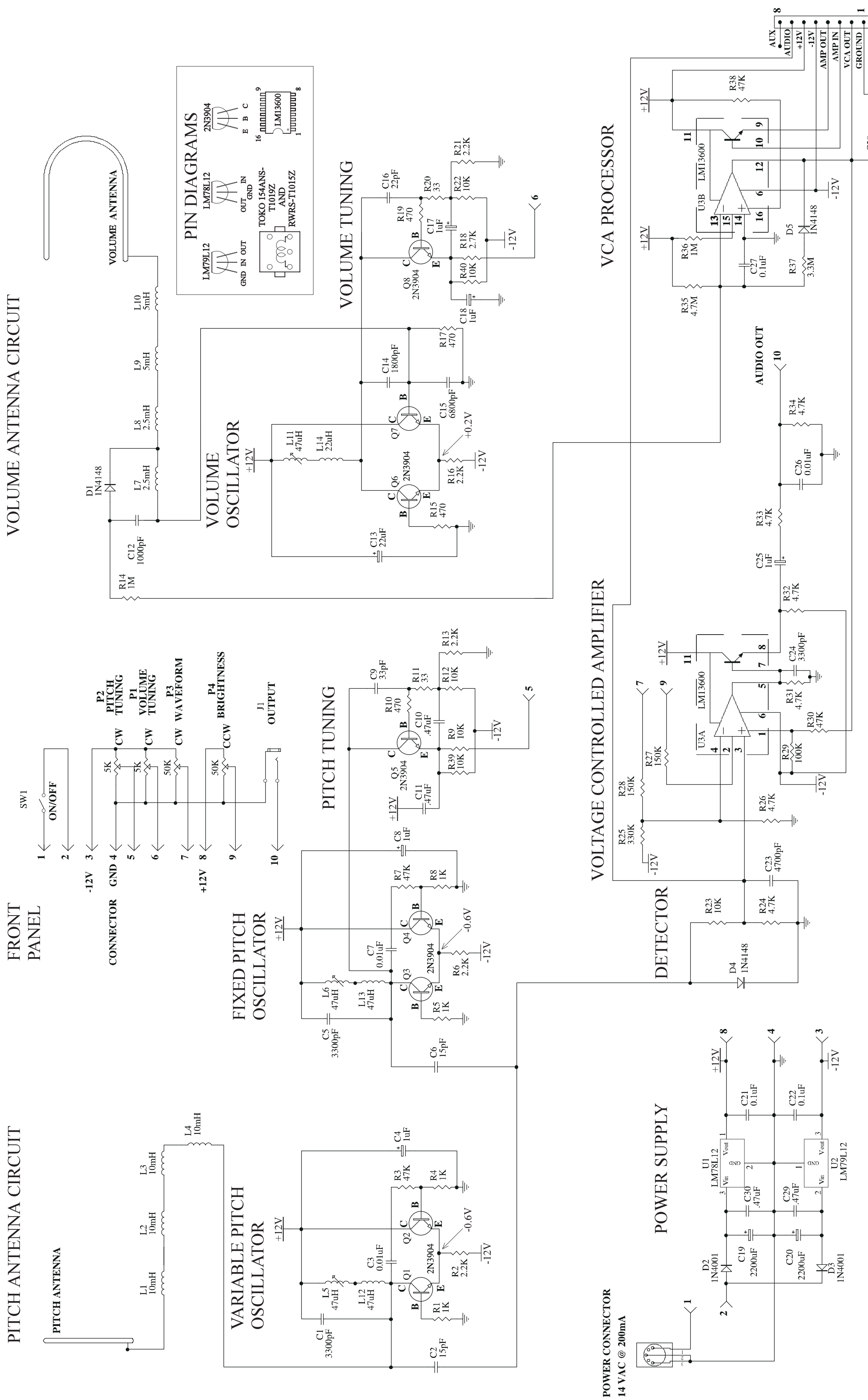


Figure 3 - Etherwave Theremin Schematic Diagram

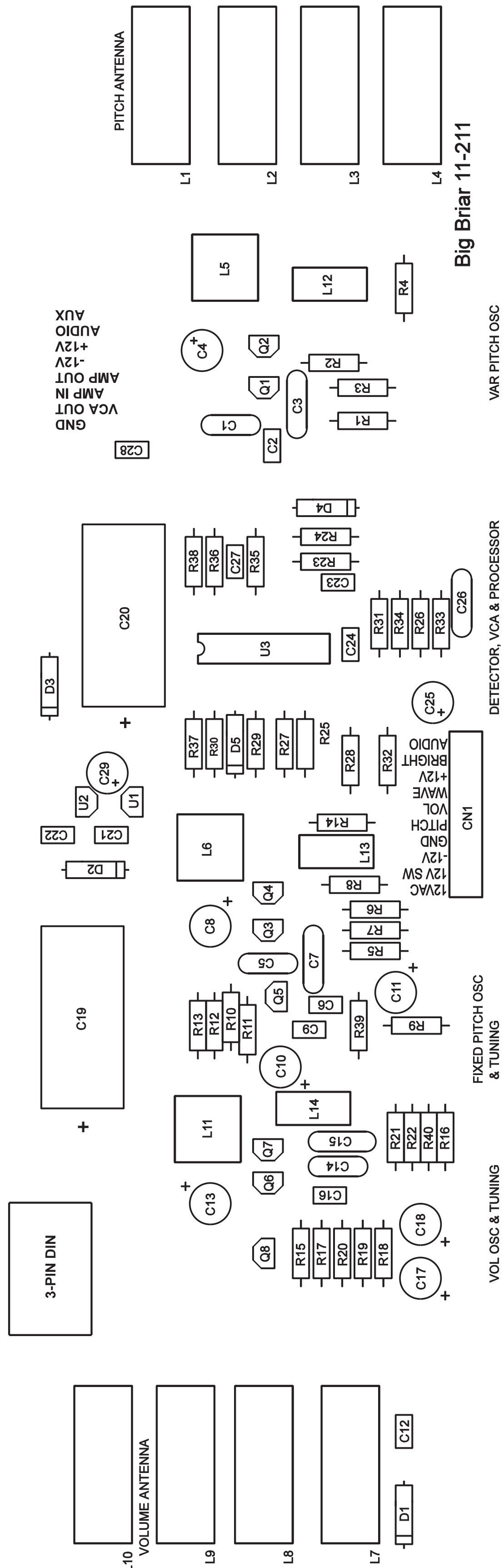


Figure 4 - Component Layout of Etherwave Circuit Board

frequency of L5, L12, and C1. When the variable pitch oscillator is tuned properly and the player's hand is away from the pitch antenna, the resonant frequency of the pitch antenna circuit is slightly lower than that of the variable pitch oscillator. Now, when the resonant frequency of the antenna circuit is lower than that of the oscillator circuit, the oscillator frequency is pushed higher. (The mathematics for this interaction is somewhat technical, but you can visualize it by imagining a car being pushed forward when a force is applied from the back.) In the case of a properly-tuned *Etherwave,* the 'loading' by the antenna circuit when the player's hand is away from the pitch antenna raises the frequency of the variable pitch oscillator by about three kHz. Then, as the player brings his hand near the pitch antenna, the difference between the resonant frequencies of the antenna circuit and the oscillator cicuit increases, the loading of the oscillator circuit by the antenna circuit decreases and the oscillator frequency falls to its 'natural' (unloaded) frequency.

Q3, Q4, and their associated circuitry comprise the fixed pitch oscillator, the frequency of which is determined primarily by the resonant frequency of L6, L13 and C5. Q5 and its associated cicuitry comprise the pitch tuning circuit. The circuit forms an 'active variable capacitor' which is used to make fine adjustments to the fixed pitch oscillator frequency when the instrument is being played. Front panel potentiometer P1 adjusts the current through Q5, thereby varying its active capacitance. Similarly, Q6, Q7, and their associated circuitry comprise the volume oscillator, whose frequency is determined primarily by the resonant frequency of L11, L14 and C14, plus the effect of the active variable capacitor formed by Q8 and its associated circuitry. P2 adjusts the current through Q8, thereby varying its active capacitance.

C2 and C6 combine the pitch oscillator signals, while D4, R23, R24, and C23 extract the difference frequency. C2 and C6 also provide weak coupling between the two pitch oscillators, which has the effect of synchronizing the pitch oscillators when their frequencies get very close together. This has the desirable effect of providing a stable 'zero beat', so that the instrument, once properly tuned, is silent when the player steps away from it. The audio waveform at the junction of R23 and R24 is a skewed sine wave with a peak-to-peak voltage of about 0.8 volts.

A detector consisting of D1, R14, and C12 is connected across L7 of the volume antenna circuit. When the resonant frequency of the antenna circuit is equal to the volume oscillator frequency, the DC component of the voltage at the junction of C12 and R14 is about -3 volts and decreases as the player brings his left hand near the volume antenna. This voltage is converted into a current, which is then used to control the gain of the instrument's VCA.
U3 is a 'dual operational transconductance amplifier'. Either section may be used as a VCA or a programmable op-amp. Section B is used to convert the volume control voltage to a current, which is then used to control the gain of Section A. The audio waveform is applied to the input of Section A, at a level which is high enough to clip it. This has the effect of reshaping the audio waveform from a skewed sine to a quasi-rectangular wave, which is very similar to the waveform of Theremin's original instruments. P3 varies the input resistance of Section A, which determines the amount that the audio waveform is clipped. P4 shifts the bias at the input of U3-A, which changes the waveform width and therefore the sound's timbre. C24 and C26 roll off the high frequency harmonics to give a pleasant cello-like tonal balance. The maximum level at the audio output jack is about 0 dBm (0.8V rms).

The ± 12V power supply consists of an external power adaptor which delivers 14 volts AC at 200 milliamperes to two half-wave rectifiers D2 and D3, and two voltage regulators U1 and U2.

TUNING THE PITCH CIRCUIT

The circuit board of your *Etherwave* theremin has been assembled, tested, and adjusted at the factory. However, you may find it desirable or necessary to trim the adjustments of L5, L6, or L11. For instance, you may want to set your *Etherwave* to cover a slightly different pitch range, or the finish you used for your cabinet might have slightly different electrical properties than that which we adjust the boards for at the factory.

Before tuning, clean off your workbench and move aside large conductive objects like desk lamps and test gear. Leave a clear space of two or three feet around your work area. Place the cabinet base in the middle of the cleared space, and put the pitch antenna in place.
Using a clip lead or a temporarily-soldered wire jumper, connect the two leads of C28 together. (C28 is a small capacitor, about 3" to the left of the PITCH ANTENNA connection on the *Etherwave* circuit board.) Then connect the instrument's audio

output to headphones or a monitor amplifier. Now follow these steps to adjust L5 and L6:

1. Set P1 (the Pitch Tuning control) to its mid-position.
2. Grasp and hold the pitch antenna with one hand. With the other hand, adjust L6 for zero beat. (Note: If the slug in L5 is fully counterclockwise, you have to turn it clockwise a turn or so in order to hear zero beat.) Then carefully turn L6 *counterclockwise* until you hear a pitch of about 3 kHz (3-1/2 octaves above middle C).
3. Let go of the pitch antenna. Slowly retract your hand from the vicinity of the antenna. You will hear the pitch go down.

- If the pitch does *not* go down to zero beat when you've retracted your hand completely and stepped back, then L5 is set to too low an inductance. Advance the slug in L5 (that is, turn it *clockwise*) a small amount,- perhaps 1/10 turn or so,- and repeat steps 2 and 3.
- If the pitch goes to zero beat and *then begins to ascend* as you retract your hand, then L5 is set to too high an inductance. Turn the slug in L5 *counterclockwise* a small amount, and repeat steps 2 and 3.
- If the pitch jumps abruptly to a very different pitch as you retract your hand, then L5 is set to far too high an inductance. Turn the slug in L5 *counterclockwise* perhaps 1/4 turn, and repeat steps 2 and 3.

Eventually you will converge on the proper settings of L5 and L6. The idea is to achieve settings in which the pitch is at zero beat when you've stepped away from the theremin, begins to ascend when your body is about 24" from the pitch antenna, and is about 3 kHz when your hand touches the pitch antenna. Tap lightly on L5 and L6 as you converge on the proper settings, as this will stabilize the tuning slug positions.

This completes the tuning of the Pitch Oscillators. In performance, the exact pitch tuning is achieved by adjusting the Pitch Tuning control.

TUNING THE PITCH CIRCUIT FOR DIFFERENT PITCH RANGES

With L5 and L6 set as described above, your *Etherwave* will cover a musical pitch range of five octaves - two octaves below middle C to three octaves above middle C. (Of course, it will produce tones *below* two octaves below middle C, but this part of the pitch range is not particularly useful for theremin playing.) You can retune the *Etherwave's* pitch section to cover a smaller or a larger pitch range. By covering a range up to two octaves above middle C for instance, your instrument's range will be only four octaves, but the intervals will be spaced farther apart and it will be easier for you to play a desired interval. Similarly, by covering a range of up to four octaves above middle C, your instrument will cover a six-octave range, but the intervals will be spaced very close together and proper interval production will be proportionally more difficult.

To retune your *Etherwave* for a four-octave range, first reposition the heavy wire going to the pitch antenna connector, so that it is close to the aluminum foil. (This will lower the resonant frequency of the antenna circuit.) Then repeat the tuning procedure given earlier, substituting 1.5 kHz (2-1/2 octaves above middle C) for 3 kHz in Step 2.

Similarly, to retune your *Etherwave* for a six-octave range, raise the heavy wire going to the pitch antenna connector as high as possible. Then repeat the tuning procedure, substituting 5 kHz (slightly higher than four octaves above middle C) for 3 kHz in Step 2.

TUNING THE VOLUME CIRCUIT

A. Using a Voltmeter: Remove the temporary shorting connection across C28. Connect a voltmeter from pin 12 of U3 to ground and install the volume antenna. Position your *Etherwave* so that the volume antenna is at least a foot from table tops, furniture, etc. Follow these steps to adjust L11:

1. Set the VOLUME knob to its mid position.
2. Carefully turn the slug in L11 *counterclockwise* until it is out as far as it will go. The meter should read about -12 volts.
3. Slowly turn the slug *clockwise.* At some point you will see the voltage begin to rise from -12 volts. *Stop* when the voltage goes through zero and becomes positive. You should then notice that bringing your hand near the volume

antenna lowers the voltage; the meter should read about minus 12 volts when your hand is two or three inches from the volume antenna.

This completes the tuning of the Volume Oscillator. In performance, the exact volume tuning is achieved by adjusting the Volume Tuning control.

B. Adjusting L11 without a voltmeter: Remove the temporary shorting connection across C28. Install the volume antenna. Position your *Etherwave* so that the volume antenna is at least a foot from furniture and other large objects. Follow these steps to adjust L11:

1. Set the VOLUME knob to its mid position.
2. Carefully turn the slug in L11 *counterclockwise* until it is out as far as it will go. Then turn on your amplifier and set its volume control so that the theremin tone will be audible but soft.
3. Slowly turn the slug *clockwise.* At some point you will hear the theremin tone. As you turn the slug in L11, the tone will get louder, reach a maximum loudness, and then get softer. Turn the slug back to the maximum loudness, and notice how loud the tone is.
4. Slowly turn the slug *counterclockwise* until the tone is about half its maximum loudness. You should then notice that bringing your hand near the volume antenna lowers the volume, and the tone is complete silent when your hand is two or three inches from the volume antenna.

This completes the tuning of the Volume Oscillator. In performance, the exact volume tuning is achieved by adjusting the Volume Tuning control.

WHY IS THE POWER ADAPTOR GROUNDED?

In order for any hand-capacitance device to work properly, there has to be a good path for high frequency currents to flow to ground. Older vacuum tube theremins used large power transformers, and these provided high frequency ground paths because of the large capacitances between windings.

Transistor theremins use much less power than their vacuum-tube ancestors, and their power transformers are therefore much smaller. Under certain conditions, a supplementary ground path is needed for stable operation and good tone color. For this reason, the power adaptor that is supplied with your Etherwave provides a direct connection to ground. That is the purpose of the third prong on the power adaptor.

If you are using your Etherwave with an amplifier that also has a direct connection to ground (i.e. a three-prong power plug), you may experience a small amount of hum from the ground loop,- especially if your amplifier is plugged in to a different power circuit than your Etherwave. If this happens, simply use a 'ground-lifter' 3-prong-to-2-prong adaptor on your Etherwave power adaptor.

CAN I USE BATTERY POWER?

Your Etherwave must be grounded *somehow.* If you want to battery-power your Etherwave while it is connected to headphones, or to an ungrounded battery-powered amplifier, you must provide a connection to ground or to some sort of a large metallic structure like a steel building frame or plumbing system.

If you use batteries, you must supply between 15 and 25 volts to each of the Etherwave's power regulators. Apply the positive voltage to the (+) side of C19 on the Etherwave circuit board, the negative voltage to the (-) side of C20, and the common to ground. A double-pole switch may be used to turn on the batteries. Figure 5 shows how to hook four 9-volt batteries to power your Etherwave in the absence of regular AC power. Keep in mind that the Etherwave draws about 30 milliamperes, so a set of four regular 9-volt batteries will last for only a few hours.

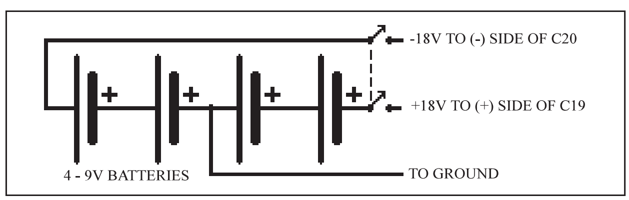


Figure 5 - Battery power circuit for the Etherwave

CUSTOMIZING YOUR *ETHERWAVE*

Here are two simple changes to the *Etherwave* that you can implement simply by changing a few components on the *Etherwave* circuit board. If you're not familiar with removing and replacing components on circuit boards, then follow these steps carefully:

1. Using a diagonal cutting pliers, cut away as much of the component to be removed as possible.

2. Using a soldering iron, heat one of the circuit board pads from which the unwanted component was just cut, until the solder is molten. Then, while the solder is still molten, tap the circuit board on a hard surface to knock out the molten solder and the short stub of wire from the removed component. Alternately, you may use a 'solder-sucker' tool or 'solder-wick' to remove the molten solder. The purpose of this step is to remove the stub of component wire and all the solder from the hole in the pad. Do not overheat the pad. Before proceeding past this step, inspect carefully for solder splashes on the circuit board.

3. Repeat the above step on the other pad(s) from which the unwanted component was cut away.

4. Bend the wires of the new component so that it slips into the desired location. Then solder the new component in place and cut off the excess wire.

LOWERING THE LEVEL OF THE *ETHERWAVE'S* AUDIO OUTPUT SO IT WILL WORK WITH A GUITAR OR BASS AMPLIFIER

The *Etherwave's* maximum audio output is normally 0.5 volts to 1.0 volts RMS. This is what is commonly known as 'line level', and is the correct voltage level for keyboard amplifiers, line level inputs of mixing consoles, and 'aux' inputs of home stereo amplifiers. However, it is often too high for guitar and bass amplifier inputs, which are designed for signals that are much weaker.

To reduce the *Etherwave's* audio output level so that it will not overload the input of a guitar amplifier, remove R33 (4.7K resistor) and replace it with a 47K resistor. Figure 4 shows the location of R33.

REVERSING THE RESPONSE DIRECTION OF THE ETHERWAVE'S VOLUME ANTENNA

Authentic theremins are designed so that the volume is loudest when the player's left hand is away from the volume antenna, and silent when the player's left hand is close to the volume antenna. This enables the player to articulate individual notes with quick, short movements of the left hand toward the volume antenna, and to use large, graceful movements to impart expressive dynamics.

In certain applications, it may be desirable for the volume antenna to operate so that the instrument is silent when the player's left hand is away from the volume antenna, and loudest when the player's left hand is close to the volume antenna. An example is a demonstration setup in which the instrument is silent when people are walking around it, and becomes audible only when a player brings his left hand within a few inches of the volume antenna.

Follow these instructions to reverse the response direction of the *Etherwave's* volume antenna:

1. Remove Diode D5.

2. Remove the LM13600 chip from its socket, bend pins 13 and 14 up so they will not make contact with the socket, and reinstall the chip in its socket.

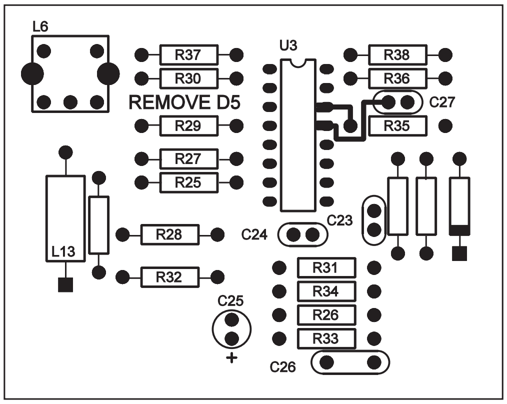
3. Solder a short piece of insulated wire from pin 13 to the left side of C27.

4. Solder a short piece of insulated wire from pin 14 to the left side of R35.

5. Retune L11 for desired volume antenna response.

Figure 6 shows what the *Etherwave* board should look like after the modification.

Figure 6 - Reversing the Etherwave's volume antenna



USING A PEDAL TO CONTROL VOLUME

Under some special conditions, you may find it desirable to control your Etherwave's volume from a pedal or an external potentiometer, rather than with the instrument's volume antenna. For instance, you may wish to play a keyboard with your left hand while playing the Etherwave's pitch with your right hand.

The most straightforward way of using a pedal for the Etherwave's volume control is to connect the VCA OUT voltage to +12V, thereby setting the Etherwave's audio output to maximum level, and then feeding the audio output through a conventional volume control pedal. To connect the VCA OUT voltage to to +12V, carefully solder a short wire from pad #2 to pad #6 of the auxiliary header. (See the description of the Auxiliary Header which follows.)

HOT-RODDING YOUR *ETHERWAVE*

The Etherwave circuit board has pads for an auxiliary header with 0.1" pin spacing. Looking down on the board from the front of the instrument, you will see the pads along the upper edge. These pads provide power and signals for use by external custom circuitry. You will find it convenient to connect to these pads by soldering a header (for instance Molex 22-03-2081) in the pads, and equipping your external circuitry with a mating connector.

There are six pads on circuit boards built before July, 1996, and eight pads on boards built starting July, 1996. Starting from the left, the pads are:

PAD NUMBER	FUNCTION
1	**GROUND**
2	**VCA OUT**
3	**AMP IN** (incorrectly marked 'AMP OUT' on earlier boards)
4	**AMP OUT** (incorrectly marked 'AMP IN' on earlier boards)
5	**-12 V** (-12 volts, 25 milliamperes maximum)
6	**+12 V** (+12 volts, 25 milliamperes maximum)
7	**AUDIO** (signal across R24, only on later boards)
8	**AUX** (for use by experimenter, only on later boards)

The VCA OUT pad goes from -12V (silence) to +12V (loudest tone) as you vary the position of your hand near the volume antenna. It is an unbuffered, high impedance point, so if you want to use this signal, you should not load it with an impedance of less than 100K.

The AMP IN and AMP OUT pads are the base and emitter, respectively, of a transistor (actually two transistors connected in a 'Darlington' configuration) that is part of U3. The collector of the transistor is permanently connected to +12V. You can use this transistor as an emitter follower to buffer either the VCA OUT or selected other points in the Etherwave circuit. The VOLUME CONTROL VOLTAGE OUTPUT circuit, described later, is an example of how to use the transistor which is connected to AMP IN and AMP OUT.

The +12V and -12V pads may be used to supply up to 25 milliamperes for powering external circuits.

Two additional pads are provided on circuit boards built after July 1, 1996. They are AUDIO and AUX. AUDIO provides the same signal that feeds the Etherwave's voltage-controlled amplifier. It's useful for amplifying and processing the Etherwave's tone before it is shaped by the VCA. The AUX pad is connected only to another pad on the Etherwave board, and is useful for providing a connection of your choice through the auxiliary header.

OUTPUT AMPLIFIER FOR TUNER

The addition of an audio output for an electronic tuner will enable you to see exactly what pitch you're about to play, even before you take your hand away from the volume antenna to start the tone.
In Figure 7, R23, R24, D4 and C23 are components on the Etherwave board. The audio signal across R24 is a constant 600 millivolts peak-to-peak. This signal overdrives the LM3080, producing a clean, rounded rectangular wave of about 1.4 volts peak-to-peak. The output appears at pin 6 of the LM3080. It may be connected directly to the tuner input, or to a small jack into which the tuner may be plugged. The jack may be mounted on the front panel. You will need to carefully drill a 1/4" hole for it, positioning it so it does not get in the way of existing panel components

The LM3080 amplifier circuit may be built on a small piece of prototyping circuit board material, and then mounted inside the Etherwave cabinet. All connections to the Etherwave circuitry are made through the Etherwave's auxiliary header, which you must install yourself on the Etherwave board. The one exception to this is the connection to the junction of R23 and R24 on earlier boards, which does not go through the header and which you must solder directly to R24. (See Figure 7.)

Parts list for Output Amplifier for Tuner:
C1 1nF 50V 10% ceramic capacitor
R1 10 kΩ 1/4 watt 5% resistor
R2 47 kΩ 1/4 watt 5% resistor
R3 1 kΩ 1/4 watt 5% resistor
R4 220 kΩ 1/4 watt 5% resistor
U1 LM3080N or CA3080E integrated circuit
6 or 8-Pin PCB-mount header
(Molex # 22-23-2061 or 22-23-2081)
Prototyping board
(Radio Shack # 276-1396 or 276-147A)
Miniature panel-mount phone jack
(Radio Shack # 274-251A)

OUTPUT AMPLIFIER FOR HEADPHONES

The regular audio output of the Etherwave is less than 2 volts peak-to-peak, with an output impedance of about 2.4 Kilohms. This is a good level and impedance for feeding into a line-level input of an amplifier, recorder, and mixing console, but is too weak for most headphones.

The circuit in Figure 8 boosts the Etherwave output so you can practice with headphones. The regular audio output of the Etherwave is boosted by about 20 dB. The amplifier's output is delivered to the headphones through 330 ohm resistors, which protect both the headphones and the TL081 amplifier from unexpected electrical 'surprises'. (Note: Increase the values of the protecting resistors to 1,000 ohms if the sound level in your headphones is uncomfortably loud.)

The headphone amplifier may be built on a small piece of prototyping circuit board material, mounted inside the Etherwave cabinet, and connected to the Etherwave circuit board through its auxiliary header. If your Etherwave circuit board is an earlier version, you will also need to solder a wire directly between the junction of R33 and R34 on the Etherwave board, and the input of your headphone amplifier circuit. If your Etherwave circuit board is a later version, you will need to solder a wire from the junction of R33 and R34, to the 'Aux' pad near the auxiliary header. You may then connect pin #8 of the auxiliary header to the input of your headphone amplifier.

The headphones jack may be mounted on the front panel. You will need to carefully drill a 1/4" hole for it, positioning it so it does not get in the way of existing panel components.

Parts List for Output Amplifier For Headphones
C1 100pF 50V 10% ceramic capacitor
R1 10 kΩ 1/4 watt, 5% resistor
R2 100 kΩ 1/4 watt, 5% resistor
R3, R4 330 Ω 1/4 watt, 5% resistor
U1 TL081 Operational Amplifier
1/8” Miniature stereo phone jack
(Radio Shack # 274-249A)
6 or 8-Pin PCB-mount header (Molex # 22-23-2061 or 22-23-2081)
Prototyping board (Radio Shack # 276-1396 or 276-147A)

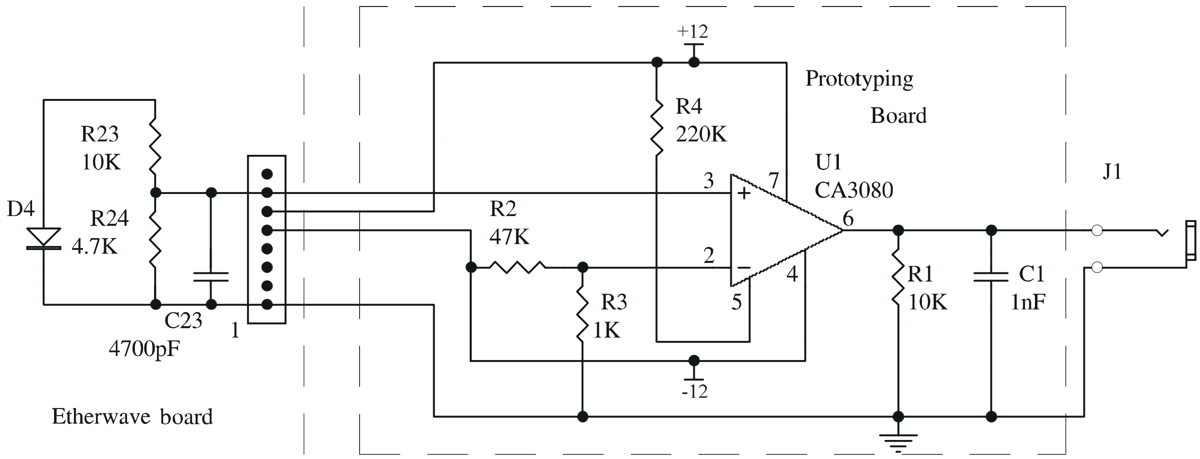


Figure 7 - Output Amplifier for Tuner

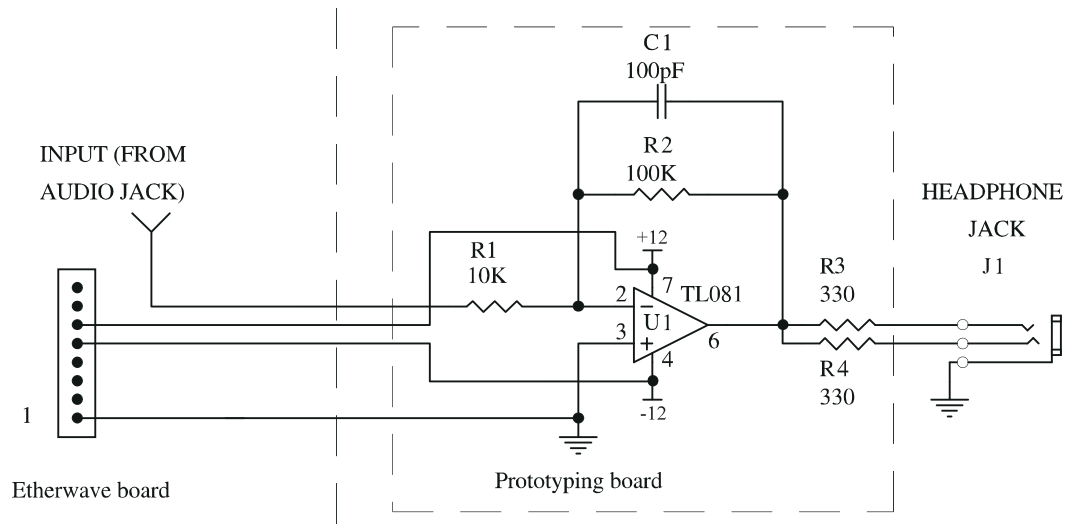


Figure 8 - Output Amplifier for Headphones

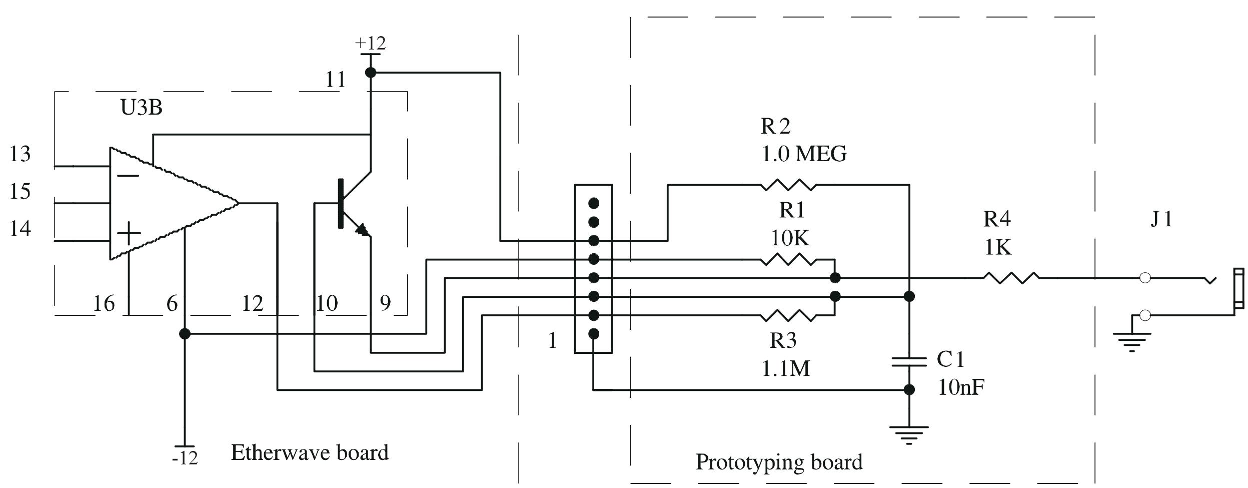


Figure 9a - Etherwave Volume CV Circuit

VOLUME CONTROL VOLTAGE (CV) OUTPUT CIRCUIT

With additional circuitry consisting of four resistors and one capacitor, you can produce a buffered control voltage that goes from +10V to zero as you bring your left hand near the Etherwave's volume antenna. You can then use this voltage as a control input to a modular analog synthesizer or similar voltage-controlled device.

Figure 9a shows the existing VCA chip on the Etherwave board, as well as the outboard circuitry that must be added. When the Etherwave is operating normally, the voltage at pin 12 of U3 goes from a maximum of +11 volts to a minimum of -11 volts as you approach the volume antenna with your left hand. This circuit point is high impedance, and is not capable of controlling outboard circuitry directly. However, there is an unused buffer transistor within U3. This transistor, plus a high impedance voltage divider consisting of outboard resistors R2 and R3, convert the high impedance voltage at pin 12 (over the range +11V to -11V) to a low impedance buffered voltage at pin 9 (over the range +10 volts to zero). R1 provides operating current to the transistor, R4 is a protective resistor, and C1 suppresses noise and hum.

R1-4 and C1 can be placed on a very small piece of prototyping board, which can then be wired in-line between the connections to the auxiliary header and the CV output jack. The jack may be mounted on or under the floor of the Etherwave's cabinet base. Figure 9b shows how the parts can be arranged on the prototyping board.

C1 10 nF 50V 10% ceramic capacitor
R1 10 kΩ 1/4 watt 5% resistor
R2 1.0 MΩ 1/4 watt 5% resistor
R3 1.1 MΩ 1/4 watt 5% resistor
R4 1 kΩ 1/4 watt 5% resistor

6 or 8-Pin PCB-mount header (Molex # 22-03-2061 or 22-23-2081)
Prototyping board (Radio Shack # 276-1396 or 276-147A)
Miniature panel-mount phone jack (Radio Shack # 274-251A)

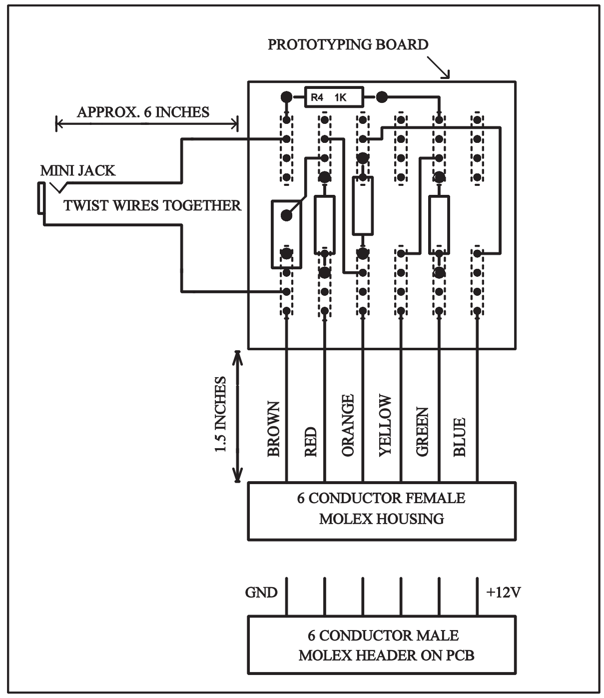


Figure 9b - Component Layout of Volume CV Board

PITCH CONTROL VOLTAGE AND GATE OUTPUT CIRCUIT

We'll now describe a high accuracy pitch-to-voltage converter circuit which you can build and then use to control the pitch of a wide variety of analog synthesis equipment from your Etherwave. In order to do this, the circuit must produce a control voltage which increases precisely one volt for every octave increase of the Etherwave's pitch. Our circuit performs this function over the Etherwave's entire pitch range with high accuracy, speed, and stability. It is somewhat more complex than the other circuits described in this manual. However, all parts except for one are inexpensive and readily-available. The one special component, a temperature-compensating resistor, is available from Big Briar. If you're an experienced 'hardware hacker', you will be able to build and test this circuit.

Figure 10 shows the circuit's schematic, while Figure 11, shows waveforms at various points in the circuit. Refer to these figures while reading the circuit description which follows.

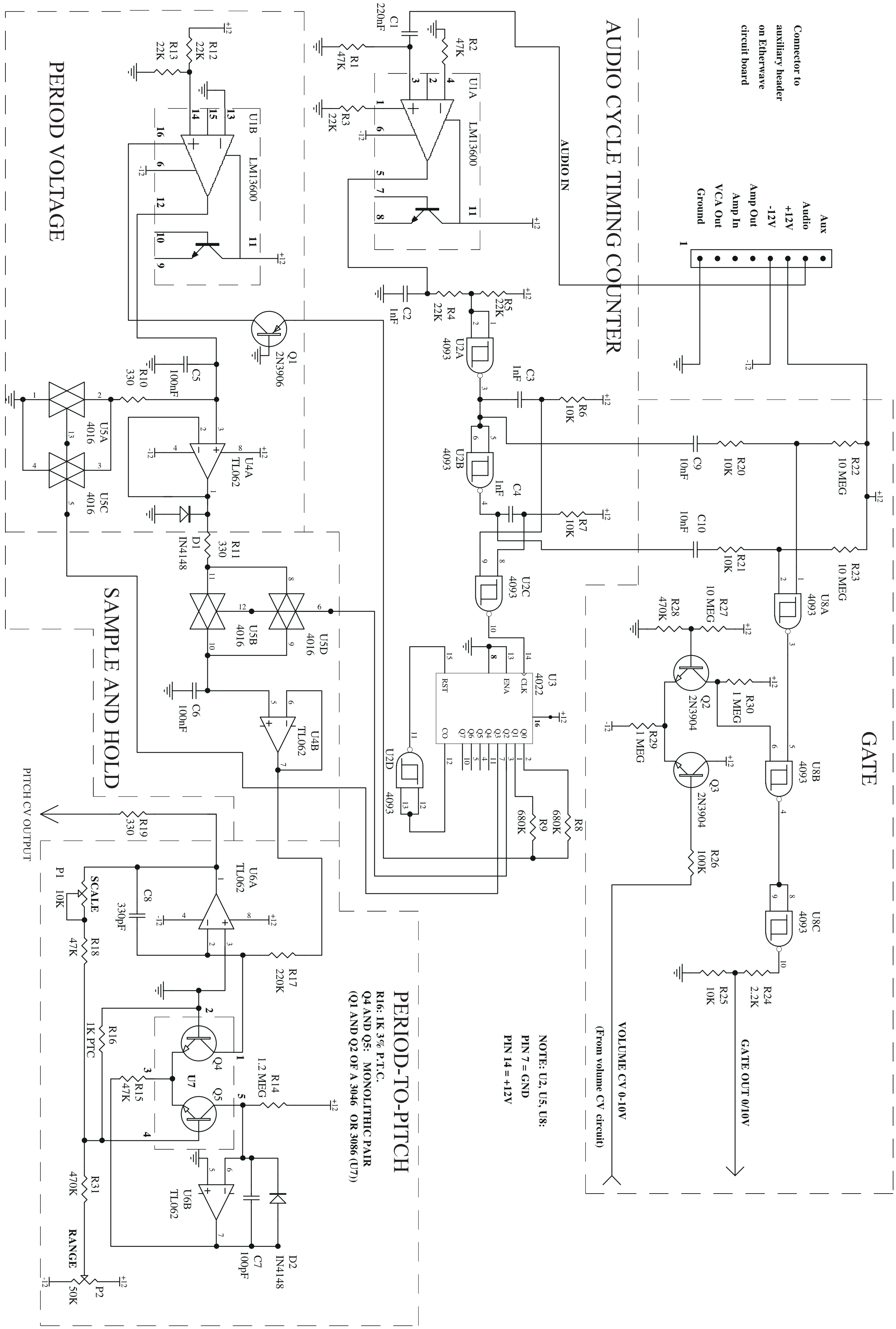


Figure 10 - Etherwave Pitch CV and Gate Output Circuit

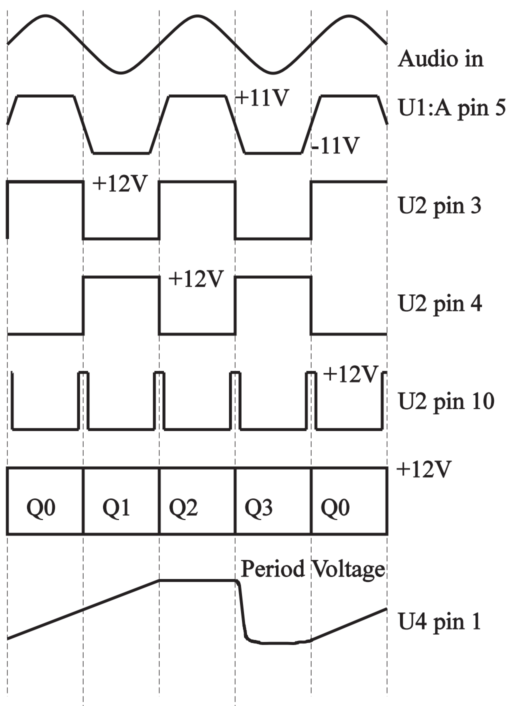


Figure 11 - Pitch CV Circuit Waveforms

The AUDIO CYCLE TIMING section divides two complete cycles of the Etherwave's audio into four time slots. The audio waveform from the Etherwave's detector is amplified by U1:A. The amplified waveform at pin 5 of U1 is about 20 volts peak-to-peak, and is somewhat clipped. U2:A and U2:B are connected as inverting Schmitt triggers. They convert the audio waveform into square waves of opposite polarities. C3-R6 and C4-R7 are differentiating networks whose outputs are skinny pulses. The output of U2:C is a series of squared-off skinny pulses, occurring at the rate of two per audio cycle. These advance the counter so that counter outputs Q0 - Q3 go on in a sequence that repeats every two cycles of audio.

The PERIOD VOLTAGE section produces a voltage, called the *period voltage,* that is proportional to the length of a single cycle of the Etherwave's audio. U1:B and its associated circuitry is a constant-current source which is turned on by counter outputs Q0 and Q1. The current charges C5. At the end of the Q1 time slot, C5 has been charging for exactly one period of the audio waveform. U4:A is a unity gain buffer, the output of which follows the voltage across C5. Switches U5:A and U5:C, which are turned on during the Q3 time slot, discharge C5 so there is no voltage across it when the next Q0 time slot begins.

The SAMPLE AND HOLD section transfers the period voltage across C5 during time slot Q2, to C6. C6 then holds the period voltage until the next Q2 time slot. Thus, the period voltage at the output of U4:B is updated every two cycles of the Etherwave's audio.

The PERIOD-TO-PITCH section takes advantage of the following property of a pair of junction transistors: the ratio of the collector currents flowing through the transistors is proportional to the exponential of the voltage difference between the two transistor bases. Without going into mathematical detail, we can say that, because the numerical relationship between period and pitch is exponential, this circuit computes the one-volt-per-octave pitch voltage from the period voltage input.

The GATE section produces a +10V gate output whenever a) the Etherwave audio frequency is more than 20 Hz or so, *and* b) the Volume CV is greater than 1/2 volt. This signal can be used to turn on envelope generators and synchronize modulating waveforms in analog synthesis equipment.

CONSTRUCTION HINTS

This entire circuit, as well as the PITCH, VOLUME, and GATE output jacks, may be built into a small untility box that can then be mounted on the microphone stand, immediately under the Etherwave. A neat connection between the Etherwave auxiliary header and this CV output circuit may be made with a short length of 8-conductor ribbon cable. You may want to cut a clearance slot on the edge of the Etherwave base to allow room for the ribbon cable to feed through the cabinet base without being pinched.

Except for R16, all electronic components are standard and are readily available from most parts distributors. R16 is a positive-temperature-coefficient resistor that compensates for normal temperature variations within Q4 and Q5. It should be mounted very near U7. Also, it is a delicate component because it is wound from extremely fine resistance wire. Handle it gently and take care not to bend the leads close to the body of the component. They're available from Big Briar. Price, including shipping, is $10.

The SCALE and RANGE adjustments should be high-quality cermet trimmers.

SETTING THE ADJUSTMENTS

When your Pitch CV circuit is working properly, the Pitch CV Output voltage should be zero volts when the Etherwave is producing a pitch one octave below middle C (130.8 Hz.), and should go up by exactly one volt for every one-octave increase in pitch. The SCALE adjustment sets the pitch voltage difference that you get when you increase pitch by one octave, while the RANGE adjustment sets the voltage that you get when you produce one octave below middle C.

The SCALE and RANGE adjustments are most easily set by feeding an audio test oscillator signal to the Audio In connection, in place of the Etherwave audio output. You should measure the test oscillator's frequency with a frequency counter, and measure the Pitch CV Output voltage with an accurate digital voltmeter.

After connecting the test equipment to your circuit as described above, connect the Etherwave and apply ±12V power by turning the Etherwave on. If you have an oscilloscope, verify that the waveforms shown in Figure 10 are present. If they are, then proceed as follows:

1. Set the test oscillator at 130 Hz. Note the voltage at the Pitch CV Output. Set the RANGE adjustment so the Pitch CV Output is exactly zero volts.
2. Set the test oscillator to 2080 Hz. Set the SCALE adjustment so that the Pitch CV output is exactly +4.00 volts.
3. Repeat steps 1. and 2. until no further adjustment is needed.

Parts list for Pitch CV and Gate Circuit

Note: Unless otherwise indicated, capacitors are 50V, 10% ceramic, and resistors are 1/4W 5%.

C1	*220nF*
C2, C3, C4	*1nF*
C5, C6	*100nF 50V 10% Polypropylene Capacitor*
C7,	*100pF*
C8	*330pF*
C9, C10	*10nF*
D1, D2	*1N4148 or 1N914B Diode*
P1	*10 k multiturn cermet trimmer (Bournes 3299Y-103)*
P2	*50 k multiturn cermet trimmer (Bournes 3299Y-503)*
Q1	*2N3906 PNP transistor*
Q2, Q3	*2N3904 NPN transistor*
R1, R2, R15, R18	*47 kΩ*
R3, R4, R5, R12, R13	*22 kΩ*
R6, R7, R20, R21, R25	*10 kΩ*
R8, R9	*680 kΩ*
R10, R11, R19	*330Ω*
R16	*1 kΩ positive temp. coeff. resistor*
R14	*1.2 MΩ*
R17	*220 kΩ*
R28, R31	*470 kΩ*
R22, R23, R27	*10 MΩ*
R24	*2.2 kΩ*
R26	*100 kΩ*
R29, R30	*1 MΩ*
U1	*LM13600N dual operational transconductance amplifier (National Semiconductor)*
U2, U8	*CD4093E Quad 2-input NAND Schmitt trigger*
U3	*CD4022E Divide-by-eight Johnson counter*
U4, U6	*TL062 Operational amplifier*
U5	*4016 Quad bilateral switch*
U7	*LM 3046 or LM3086 Transistor Array*

6 or 8-Pin PCB-mount header
(Molex # 22-23-2061 or 22-23-2081)
Prototyping board
(Radio Shack # 276-1396 or 276-147A)
Miniature panel-mount phone jacks
(Radio Shack # 274-251A)

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